

USE OF POINT-TO-POINT RADIO (MICROWAVE) IN TELEPHONY

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FIGURES 1 - 9B

TABLE 1

1. GENERAL

1.1 This section is intended to provide REA borrowers, consulting engineers, suppliers, and other interested parties with information for use in determining the application of microwave for use in telephony. It discusses the factors affecting the use of microwave equipment presently available. The factors affecting the choice of using analog or digital radio and FM or PCM multiplex are also discussed.

1.2 This issue of TE&CM 930 is a revision of Issue No. 2 (June 1966) in that the use of digital radio and PCM multiplex are discussed for microwave system considerations. Due to changing equipment costs, many equipment costs quoted in Issue No. 2 have been deleted, and costs in this issue are given only for examples. The channel capacities of radio equipment have also been updated.

2. FEDERAL COMMUNICATIONS COMMISSION REQUIREMENTS

2.1 A construction permit must be obtained from the Federal Communications Commission before a radio transmitter is installed. After installation of a radio transmitter, it must be licensed and operated according to the applicable FCC rules.

2.2 Most radio equipment used by telephone companies is licensed under Part 21, Domestic Public Radio Services. Part 21 is included in Volume VII of the FCC Rules and Regulations and may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. The management of a telephone company that is contemplating the installation of a microwave system should become familiar with Part 21.

2.21 Microwave transmitting equipment must in general be Type Accepted under Part 2 of the Commission's Rules - (Subpart J, Equipment Authorization Procedures) in order for the user to obtain a construction permit. The type acceptance procedure is usually undertaken by the equipment manufacturer when the transmitter is first developed. A list of current type-accepted equipment is published from time to time by the Office of the Chief Engineer of the FCC, entitled, "Radio Equipment List - Equipment Acceptable for Licensing". This catalog is obtainable from a contract reproduction service specified by the Chief Engineer's Office. The catalog lists manufacturers in alphabetical order with the technical parameters under which each transmitter has been type-accepted. There is provision for developmental licensing of equipment which has not yet been type-accepted.

2.22 Each of the commonly used frequency bands available to telephone companies under Part 21 regulations has a minimum traffic loading restriction intended to ensure that the radio spectrum is efficiently allocated among different users. These traffic loading restrictions require the prospective microwave user to demonstrate that within a reasonable growth period after installation, his traffic requirements will reach the minimum standard appropriate for licensing in that band.

2.3 The maintenance of microwave equipment must be performed by trained personnel holding First or Second Class FCC Commercial Radio Operator Licenses. Most manufacturers of microwave equipment conduct schools to provide technical training for customer maintenance technicians. The test equipment and methods recommended by the microwave supplier should be used to make equipment measurements.

3. CAPABILITIES OF MICROWAVE

3.1 Microwave transmission is generally defined as the transmission of those electromagnetic waves whose frequency falls approximately in the range between 1 Gigahertz and 50 Gigahertz (wavelengths of 30 cm to 6 mm). The propagation through the atmosphere of signals in this frequency range exhibits many of the properties of light, such as line-of-sight transmission, reflection from smooth surfaces, etc. Microwave systems have many applications in the telephone industry because high quality circuits can be derived for intertoll trunks, toll connecting trunks, EAS trunks, subscriber service and special services. Microwave is also suitable for transmission of black and white or color television, data, and data under voice, with negligible impairment from impulse noise, delay distortion, frequency error, frequency response, or steady state noise.

3.2 Another attractive aspect of microwave is the ease with which channels can be added or removed after the basic radio frequency (RF) and carrier multiplex equipment is installed. Certain types of RF equipment will carry 600 to 1200 or more voice channels without any change in the basic RF equipment. The problems associated with cable facilities such as physical damage, induction noise, right-of-way problems, circuit expansion limitations and similar problems are reduced with the use of microwave.

3.3 The initial cost of a microwave system depends on the type of RF and multiplex equipment used, the number of channels, the number of hops in a system, the terrain, and other factors. In some cases microwave will require a lower initial investment, provide greater reliability, and have lower operating costs and maintenance than cable facilities.

4. SITUATIONS WHERE MICROWAVE MAY BE DESIRABLE

4.1 There are at least four conditions where microwave will often be more desirable than other types of facilities. These situations are discussed in the following paragraphs.

4.2 In some cases the length of a circuit route and the long range estimate of channel requirements will result in the use of microwave being more feasible than cable facilities. The expansion capabilities of microwave are such that many channels can be added without any changes or additional cost for the RF equipment. The cost per channel for additional channels on a microwave system will sometimes be less than for circuits derived on cable facilities, and as more channels are required, the per channel cost will become less.

4.3 Another situation where microwave offers definite advantages is in areas of difficult terrain. When communications must be provided in mountainous areas, microwave can usually be provided at less cost than cable facilities. In mountainous areas, the cable route will normally be long since it usually does not take a straight-line path like microwave, but follows a winding road. The necessity of crossing obstacles such as lakes and swamps is made more practical and more economical with the use of microwave, as well as other cases where topographical characteristics make the construction of cable facilities expensive or impossible.

4.3.1 In areas where PCM cable carrier is advantageous with the exception of an obstacle such as a lake or section of ground that is too hard for buried cable, digital microwave radio can be used as an "aerial insert" to bypass the obstacle. This application of digital radio allows the PCM signals on the cable to be continued over microwave radio without the need for any analog-to-digital or digital-to-analog conversions.

4.4 In many instances it is necessary for one telephone company to connect with another company's toll circuits. When the connecting company derives its toll circuits using microwave, the other company may be required to provide microwave radio and multiplex equipment such that the two systems can meet "mid-air" on a microwave frequency basis; the

use of identical or closely similar radio equipment at both ends of such a link is recommended for ease of maintenance and administration between the connecting companies.

4.5 Microwave can also be used to provide video circuits. Most microwave equipment has sufficient bandwidth for transmission of the video portion of one television channel over each microwave RF channel. The audio for the television channel can be transmitted over the same RF channel using a subcarrier or it may be carried over a separate facility. Most microwave systems of current design will permit the application of several modulated subcarriers over the video channel without significant degradation. This frequently permits the transmission of FM stereo program material, voice and/or telemetry circuits in addition to the video sound carrier over the same RF channel as the video information.

5. COMPONENTS OF A MICROWAVE SYSTEM

5.1 Transmitters and Receivers. The basic building blocks of a microwave system are the radio frequency (RF) transmitters and receivers. These units make it possible to send and receive information at microwave frequencies. Most microwave transmitters are capable of an output power of one watt or more. A transmitter used in a terminal location has provisions for modulating the RF carrier with baseband signals from the carrier multiplex equipment. Receivers are capable of providing a useable baseband output with received microwave signal levels of -80 dbm or less. A terminal receiver includes a demodulator to provide the baseband output to the carrier multiplex.

5.2 Carrier Multiplex. The microwave RF equipment has a wide bandwidth which is capable of carrying many channels of information. These channels are derived using multiplex equipment which can combine several hundred channels for transmission over one RF channel. There are two types of multiplexing schemes: Frequency Division multiplexing and Time Division multiplexing. See paragraph 7.2 for a description of each type.

5.3 Remodulating and Heterodyne RF Repeaters. Active repeaters are used when the distance between terminal stations is too great to allow a received signal of acceptable level and also when it is necessary to insert and drop channels at points between terminal stations. An active repeater can be used at one or more intermediate points to amplify the signal to an acceptable level or to allow adding or dropping of channels. There are three types of active RF repeaters that can be used to derive a microwave system: remodulating, regenerating, and heterodyne repeaters.

5.31 The remodulating repeater demodulates the RF signal to baseband frequencies at each analog radio repeater location. The baseband information is then used to directly modulate the transmitter. This process is continued at each repeater and each time that demodulation and modulation takes place noise and distortion are added to the system. In the case of digital radio transmission, a digital repeater can best be described as a regenerating repeater, in that the received pulses that are demodulated from the incoming RF frequency trigger the generation of

new pulses to be modulated onto the succeeding transmitter, so that any pulse that has been degraded by noise is completely renewed. Thus, even though this process is continued at each repeater, noise and distortion is not added to the system, as in analog radio transmission. The noise and distortion contributed by an analog repeater can become serious in long-haul, high density ^{toll} routes where many repeaters are required, and a digital radio system could be more advantageous for this type of radio route. Since most radio systems owned by REA borrowers do not exceed four or five hops, remodulating repeaters can be used without serious degradation of the circuits. The receivers and transmitters used in a remodulating (or regenerating) repeater are the same type as those used at a terminal station, and the repeater can be actually thought of as two terminal stations connected back-to-back at the baseband level. See Figure 1 for a block diagram of a remodulating repeater.

5.32 The heterodyne repeater, used mainly for analog radio applications, converts the received radio frequency signal to an intermediate frequency (IF) signal for amplification. As an input to an up-converter the IF signal is converted to the transmit radio frequency. The output of the up-converter is normally amplified by a traveling wave tube (TWT) with an output of about 5 watts, and then fed to the transmitting antenna. There is no baseband demodulation in the path of the "through" signal, as in the case of a remodulating repeater. The elimination of the demodulation and modulation processes greatly reduces the noise and distortion in a long-haul system. The cost of a heterodyne repeater is higher than a remodulating repeater and would not be justified economically except in long-haul, high density applications. A disadvantage of the heterodyne repeater is the difficulty of inserting channels at the repeater. However, some suppliers can provide heterodyne equipment with channel insert and drop capabilities. See Figure 2 for a block diagram of a heterodyne repeater.

5.4 Passive Repeaters. A passive repeater is sometimes required when there is an obstacle such as a high mountain in the line-of-sight microwave path, where the cost, maintenance and power requirements for an active repeater would be prohibitive. The passive repeater is located in such a position as to act as a microwave mirror, reflecting the microwave signal as a mirror reflects a light beam, to bypass the obstruction. A passive repeater may be a large reflecting surface similar to a billboard, or it may be two parabolic antennas connected back-to-back through waveguide. Both types are used to change the direction of a microwave signal. The passive repeater does not use tubes, transistors, or other active devices and therefore requires no power source unless heating is necessary to prevent ice from accumulating on the antenna surfaces.

5.41 Another type of repeater that is in use is an RF repeater which receives and amplifies a microwave signal and redirects it along another route. It is essentially two parabolic antennas connected back-to-back through an RF amplifier, making this repeater arrangement much more efficient than two parabolic antennas connected directly. No frequency changing is required like it is in an active repeater, and power requirements of the RF repeater are such that solar energy can be used to power the repeater efficiently and economically. In many instances,

the cost of this type of repeater is substantially less than the bill-board passive repeater.

5.5 Antennas. A parabolic or horn antenna is used in microwave systems to concentrate radiated energy into a narrow beam for transmission through the air. This results in the most efficient transmission of radiated power with a minimum of interference. An effective gain of 25 to 48 dB over an omni-directional antenna is possible depending upon the size of the antenna and the microwave frequency used.

5.6 Radomes. A radome is a protective covering used to prevent snow, ice, water, or debris from accumulating on a microwave antenna. Heated radomes are available for use in areas where severe ice and snow conditions exist.

5.7 Transmission Lines. Transmission lines provide the means of coupling the transmitter and receiver to the antenna. There are two types currently available: waveguide and coaxial cable. The radiated output power of the transmitter will be substantially reduced if the transmission line is incorrectly used or if its length is too long, so precautions should be taken to use the correct type of line for the radio equipment used, and to keep all transmission line lengths short.

5.71 Waveguide. A waveguide is a hollow metal duct which conducts electromagnetic energy. This type of transmission line can be used for distances of a few feet up to several hundred feet. A typical type of waveguide has a loss from about 1.7 dB per hundred feet at 6 Gigahertz (GHz) to about 3.0 dB per hundred feet at 11 GHz. It is used at microwave frequencies above 2 GHz and can have either a rectangular, elliptical, or circular cross-section, depending upon the system operation requirements. The length of a waveguide run is more critical at higher frequencies since attenuation increases with frequency.

5.72 Coaxial Cable. At low microwave frequencies, 2 GHz or less, coaxial cable can be used as the connecting facility between the transmitter, receiver and antenna instead of waveguide. The loss of coaxial cable depends on the type of conductor, the cable diameter, the type of dielectric, and the operating frequency. Coaxial cable with a diameter of one inch or more should be used for long cable runs; 7/8" diameter coax can be used satisfactorily for short runs. The coaxial cable can have either an air or expanded polyethylene (foam) dielectric between conductors, however, the air dielectric coaxial cable has less attenuation for a given diameter. In general, air dielectric coaxial cable is used with higher capacity analog systems because the return loss characteristics of foam dielectric lines may be a significant distortion contributor in such systems. This is not usually a consideration in systems of low channel capacity, or in digital systems, which are considerably less sensitive to echo distortion in the transmission line. The cost of coaxial cable is less than waveguide and should be used when possible. Extreme attenuation of radio signals above 2 GHz in the coaxial cable generally prohibits its use at the higher microwave frequency bands.

5.8 Reflectors. A passive reflector can sometimes be used in systems operating at 6 GHz and above, when a tall tower is necessary, in place of using long runs of waveguide connected to a parabolic antenna at the top of the tower. A reflector may be mounted at a 45 degree angle at the top of the tower, while the antenna is mounted horizontally at the base of the tower, aimed at the reflector. The microwave signal is radiated from the antenna, reflected off the reflector, and sent in a direction of propagation to the other end of the radio path, just as though the antenna was radiating directly from the top of the tower. However, this type of "periscope" antenna system will not be authorized by the FCC under ordinary circumstances because of its interference potential in a congested frequency band. An extraordinary circumstance would be an application where the periscope antenna could be used in an area where no frequency congestion is likely to occur, and substantial cost savings could be realized over using waveguide or coaxial cable. In general, the periscope antenna should be considered only as a last resort.

5.9 Towers. The towers used in microwave systems must be rigid to prevent antenna deflection during wind or ice loading conditions. Guyed or self-supporting towers are available for use on microwave systems. A guyed tower is about one-third the cost (per foot, installed) of a self-supporting tower, but in some cases the difficulty of acquiring enough land for guying prohibits the use of guyed towers. The height of the tower is determined by the terrain, the microwave frequency band used, the propagation characteristics, the distance between the transmitting and receiving ends of a path, and the required reliability. The tower must be high enough to provide a line-of-sight-path above any obstructions. If reflection interference is a problem, the antenna mounting heights are critical and the optimum height may be less than the maximum height available on the tower.

5.10 Buildings. Microwave equipment should be located in the central office equipment building when possible. There are some situations, however, when RF equipment must be located remotely from a central office building, as in the case of an active RF repeater. In these situations some type of building must usually be provided for equipment protection. Usually a simple prefabricated building is sufficient. Where temperature and humidity variations exceed the operating limits of the microwave equipment, a heater or air conditioner is required to keep the equipment within its operating temperature range.

5.11 Primary and Standby Power Equipment. Primary power sources for RF equipment may be d.c. or a.c. as specified by the purchaser. Central office batteries or 117 volts a.c. commercial power may be used. In some cases, thermoelectric generators or fuel cells can be used when the power requirements of the microwave equipment are low. Standby power equipment should be provided at microwave terminals or active repeater locations to maintain system operation in the event of a commercial power failure. Communication circuits are very important during times of emergency such as storms, floods and other disasters which may cause commercial power outages. Therefore, it is imperative that some type of standby power source be available for circuits derived by microwave.

When microwave equipment is located in a central office building, standby power is usually available from central office equipment batteries or an engine-generator. However, at remote sites standby power must be provided specifically for the microwave. The stand-by power source may be batteries, an engine-generator or in some cases a thermoelectric generator, fuel cell or solar.

5.12 Alarm Systems. When a microwave system has remote unattended stations, it is desirable to have an alarm system which will report faults from the remote location to an attended office via the microwave signal. These alarms will expedite the maintenance of microwave systems and reduce the circuit outage time. Where alarms from a large number of unattended stations are reported to a central maintenance control center, consideration is often given to a computer-based alarm reporting system which prints out all changes in status at each station with time and date information.

6. MICROWAVE EQUIPMENT ARRANGEMENTS

6.1 Basic Equipment Arrangement. A microwave terminal is located at each end of a system and the basic arrangement consists of one transmitter and one receiver. An active remodulating microwave repeater can be thought of as two terminals back-to-back and a basic repeater arrangement consists of two transmitters and two receivers. See Figure 4.

6.11 The basic equipment arrangement is used when it is not necessary to provide duplicate equipment for protection against equipment outages or path outages. This arrangement is not normally used by the telephone companies since standby or diversity equipment is desirable to provide increased system reliability.

6.2 Hot Standby Arrangement. Hot standby is an arrangement where two transmitters are on and operating at the same frequency but only one is connected to the antenna. If the operating transmitter fails, the second or standby unit is automatically connected to the antenna and the defective transmitter is disconnected. The switching of transmitters occurs in a few milliseconds after sensing equipment has determined that a unit is defective. Two receivers are used and both are permanently connected to the antenna. The two receiver outputs are combined into one resultant signal. See Figure 5 for an example of a hot-standby arrangement. Hot standby provides increased equipment reliability, but does not increase propagation reliability. A variation of the hot standby arrangement involves the main and standby transmitters continuously feeding the antenna in a phase-locked configuration; fault conditions then cause the disconnection of the faulty transmitter. This arrangement has an RF power increase of 3 dB under normal conditions over the single transmitter output.

6.3 Space Diversity. For improvements in propagation reliability, a space diversity antenna arrangement can be used. In a space diversity system, one transmitter and its associated antenna radiates on a transmit frequency. This signal is received by two receivers which are tuned to the same frequency but connected to separate antennas located at different positions on the tower. The receiver output signals can be

combined to give a composite output, or switching can be done between receivers, keeping the receiver with the best signal to noise ratio (or Bit-Error-Rate in the case of a digital radio system) connected to the line. Vertical spacing between the two receiving antennas should be approximately 60 to 80 feet at 2 GHz, 30 to 40 feet at 6 GHz and 25 to 30 feet at 11 GHz. Space diversity provides a substantial increase in reliability, especially over highly reflective surfaces such as water or desert. The necessity of two receiving antennas, two receiving waveguide runs, strong towers because of the two antennas and a taller tower required to give the necessary antenna spacing tends to make space diversity an expensive means of increased path reliability. See Figure 6 for a diagram of a space diversity arrangement.

6.4 Frequency Diversity. A frequency diversity arrangement can be used at microwave frequencies above 2 GHz when equipment and propagation reliability is desired and required communications cannot practically be achieved by other means. (Refer to the FCC Rules and Regulations, Part 21, Section 21.100(c).) This method increases the total system reliability by providing both path and equipment duplication. Two transmitters are on the air simultaneously and both are modulated with the same signal but are tuned to different radio frequencies. The different frequencies can be either within the same operating frequency band, or in two different operating frequency bands. Both transmitters are connected to the same antenna which radiates the signals to the far-end of the path. At the far-end of the path there are two receivers and each receiver accepts the one oncoming signal to which it is tuned. Each receiver then provides as an output the signal which modulated the transmitters. The two outputs are then combined using a combiner device to provide one output signal to the multiplex. See Figure 7.

6.41 Combiners are used in analog radio applications to continuously monitor and combine the outputs of the two receivers so that the signal-to-noise ratio of the resultant output is as good or better than that of the best receiver. This is accomplished through either active or passive circuitry in the baseband path which limits or removes the contribution to the output signal from the noisier receiver so that the quieter signal predominates. If the receivers' output signal to-noise ratios are equal, the signal-to-noise ratio of the combiner output is improved by 3 dB.

6.42 A frequency diversity system provides increased equipment reliability as a result of two transmitter-receiver combinations and increased propagation reliability as a result of using two different microwave transmitting frequencies on the air simultaneously. Studies and measurements have been made which indicate that increased propagation reliability is realized when two transmitters with a frequency separation of at least 2% to 5% are used. The amount of frequency separation is mainly determined by the availability of frequencies but the minimum separation for effective propagation protection is generally regarded as 2%.

7. EQUIPMENT PRESENTLY AVAILABLE FOR COMMON CARRIERS

7.1 Radio Frequency Equipment. RF equipment is available for the 2, 4, 6, and 11 GHz common carrier microwave frequency bands. This equipment is all solid-state (except for some models that incorporate traveling wave tube final amplifiers for higher transmitter power output), has low power consumption, and requires little maintenance. These features are particularly important when using radio in remote areas. Digital and analog radios are basically equivalent types of equipment except for modulation schemes.

7.11 2GHz Microwave. Current 2 GHz RF equipment is capable of carrying up to 252 analog multiplex channels, or 144 digital multiplex channels on a single polarization. It is likely that the maximum number of digital channels will increase in the future because of improvements in technology. Propagation of radio waves at 2 GHz has higher reliability against multipath fading and is often less subject to ground reflections than higher frequency bands; it is, therefore, preferable in difficult propagation situations. The situations most appropriate for the use of 2 GHz equipment are where only a relatively few toll or EAS trunks are required to serve an exchange, where a few special circuits must be provided for a customer, and where small groups of isolated subscribers are to be provided service. The important point to remember when considering the use of 2 GHz RF equipment is whether it is capable of providing initial and future channel requirements. If a five year forecast shows a greater requirement of circuits than the capacity of 2 GHz equipment, the use of a higher frequency band should be considered. If the minimum five year channel capacity requirements of the higher frequencies cannot be met as specified in the FCC Rules and Regulations, Part 21, a second RF channel at 2 GHz should be considered.

7.12 4 GHz Microwave. This band is used primarily by the Bell System for long-haul high density toll routes and has not been used very much by independent telephone companies. However, 4 GHz equipment is available to independent telephone companies from microwave equipment manufacturers. Most of it is the heterodyne repeater type of equipment having a capacity of 1200 or more channels.

7.13 6 GHz Microwave: Six GHz RF equipment can be used to carry a large number of channels for long distances. Radio paths at 6 GHz can be longer than paths at 11 GHz because the 6 GHz radio wave is not affected as much by rain attenuation. The channel capacity of current 6 GHz equipment is as high as 1800 channels, using a 300 MHz bandwidth. To obtain FCC approval to use this frequency band, a minimum five year channel requirement of 900 channels must be shown. The cost of 6 GHz equipment is 30% to 80% higher than 2 GHz equipment. High quality circuits for short, as well as long haul applications can be obtained.

7.14 11 GHz Microwave. In geographic areas of moderate to heavy rainfall, the 11 GHz microwave frequency band should be used only on radio paths not more than 15 miles in length. At 11 GHz, rainfall effectively attenuates the radio signal because absorptions and reflections of the radio waves by raindrops occur, due to the proportional geometries of raindrops and the 11 GHz wavelength. In areas of slight rainfall longer radio paths can be used. In any instance, propagation studies should be made to determine the effects of rainfall on an 11 GHz signal for each path studied.

7.141 The channel capacity of current 11 GHz equipment is as high as 2400 channels in a 40 MHz bandwidth. For smaller channel requirements, lower cost equipment is also available having half the channel capacity in a 20 MHz bandwidth. If the FCC requirement for a five year channel capacity of 900 channels at 6 GHz cannot be met and a 2 GHz frequency cannot be obtained or its capacity too small, a light route 11 GHz radio with a 20 MHz bandwidth could possibly be feasible. The FCC requires that a 20 MHz RF channel at 11 GHz be loaded with 240 voice channels within 5 years after installation. The cost of 11 GHz equipment is slightly higher than 6 GHz equipment.

7.2 Carrier Multiplexing Equipment

7.21 General Considerations of Carrier Multiplex. Carrier multiplex is used to derive voice or equivalent channels on the microwave baseband. The channels may either be time-division multiplexed onto the carrier when digital carrier is used, or frequency division multiplexed, when analog carrier is used. (See the following discussion on multiplexing techniques.) The equipment can be used to derive a few channels or hundreds of channels. Some types of equipment are used to derive toll, EAS, data or various special circuits while other types can be used for subscriber service. Carrier multiplex equipment may be located within a few feet of the RF equipment or it may be several miles away and connected by coaxial cable, paired cable or video pairs. Carrier multiplex equipment which meets REA specification PE-60 is suitable for toll, EAS, or data circuits.

7.22 Frequency Division Multiplexed (FDM) Carrier. FDM carrier that is used on wire line carrier circuits can also be frequency modulated onto microwave radio at the group, supergroup or mastergroup levels. Refer to Section 934 for information on multiplexing hierarchy. This is known as analog radio transmission. The number of FDM channels that can be transmitted over radio depends upon the RF bandwidth that is available (generally determined by the radio frequency used), and the type of multiplex used, either low-density or high-density. For low density application a double-sideband type of modulation may be used, while single sideband, suppressed carrier (SSBSC) modulation is used for high density multiplex.

7.23 Time Division Multiplexed (TDM) Carrier. Pulse Code Modulation (PCM) carrier is a form of TDM. PCM carrier can be transmitted over microwave radio at a T1, T2, T3, or higher rate. The carrier can be either frequency modulated or phase modulated onto the RF carrier, but phase modulation is associated with a true digital radio, offering a better noise advantage with less RF power required. There are also many techniques used with the modulations of the radio to increase digital channel capacity. These deal with multi-amplitude level transmission or phasing of the data line inputs to increase the bit rate over a given RF bandwidth. Digital PCM multiplex costs are about one-third the cost of analog FDM multiplex.

7.24 Types of Carrier Multiplex Signalling. There are several types of signalling that are used with microwave carrier multiplex for telephone applications. These are E & M out-of-band, E & M inband and in some cases common channel interoffice signalling (CCIS).

7.241 When E & M inband signalling is used, a frequency within the voice frequency band of a channel is chosen as the signalling tone. This frequency is normally 2600 Hertz.

7.242 E & M out-of-band signalling generally uses a single tone which is outside of the voice frequency bandpass of the multiplex channels. The frequency of the signalling tone depends on the channel bandpass but the most used frequency is 3825 Hertz (this is the standard CCITT frequency). In some types of equipment using out-of-band signalling, two frequencies are shifted back and forth to produce signalling pulses.

7.243 Common channel interoffice signalling can be used on high density trunk circuits by allowing a certain number of channels or channel groups to be used only to transmit signalling tones. The voice or data information is transmitted over one channel while the signalling is sent over another channel. At the terminating end, the information and signalling are recombined.

7.244 Signalling on PCM multiplex is accomplished by coding the least significant bit in every sixth frame with signalling information (a frame contains 8 PCM bits that encode a voltage level of information). A pulse or "no pulse" condition signifies on-hook or off-hook conditions.

7.25 Frequencies of Carrier Multiplex Equipment. The operating frequencies of analog multiplex equipment are not completely standardized but often vary with types of equipment. Low density multiplex (on the order of 12 channels) from various suppliers are generally not frequency compatible with each other. Most higher density equipment conforms to the CCITT (Consulative Committee on International Telephone and Telegraph) recommendations or to the Western Electric "L" frequency allocations and this offers some degree of standardization.

7.251 All digital carrier multiplex used for trunk circuits are the "T" type, which uses eight-bit pulse-code-modulation to convey

signalling and message information. There are no operating frequency considerations for digital carrier, but a compatible end-to-end transmitted bit rate must be realized in order to synchronize clock circuits that decode and encode information in a timed manner. For T carrier, an increase of channel capacity increases the transmitted bit rate, which in turn increases the RF spectrum that is occupied by the carrier signal. The digital channel is given a slot in time, while the analog channel is given a slot in the carrier frequency spectrum.

8. MICROWAVE SYSTEM CONSIDERATIONS

8.1 The design of a microwave system involves engineering for adequate technical operating specifications at minimum cost. It is possible to over-engineer a system at a great expense, when the same operating results could have been obtained without a lot of extras added and at less cost. Several design approaches should be examined before making a final decision. This can be done by examining different tower heights, different antenna sizes, different repeater locations, or even comparing the use of digital or analog modulation.

8.2 Microwave system designs and costs are usually based on either ideal or average radio frequency propagation conditions. Ideal and average propagation conditions refer to the atmospheric conditions which are prevalent in an area. Ideal propagation is generally prevalent in hilly and mountainous areas where the air is in constant turbulence, ground reflections of the radio waves are at a minimum, and the radio wave is not diffracted from its line-of-sight path. This type path is economical to design for acceptable reliability. Average propagation conditions occur over plains and rolling hills where multipath reflections and radio beam diffraction occur more often. System design considerations must include the probability of these occurrences, increasing overall system cost. In some cases, paths with ideal propagation conditions will require a passive repeater to bypass obstacles such as mountains in the path. The cost of these paths may be higher than for a system over a path with average propagation which has no obstructions. Paths that go over bodies of water or flat land, or are in areas of high humidity are in the worst case propagation conditions and usually require special considerations, such as the use of space diversity, for protection against fading outages. TE&CM 931 covers microwave path engineering in more detail.

9. CHOOSING BETWEEN AN ANALOG OR DIGITAL RADIO SYSTEM.

9.1 In certain instances, the use of radio may prove to be technically and economically feasible over wireline facilities. The first step in system planning is to examine various plans on a system basis, as well as on a present worth of annual cost (PWAC) basis. These plans could incorporate combinations of cable and digital radio, all radio, cable and analog radio, all cable, etc. After various plans have been studied, the plan that offers the best technical and economic feasibility should be used. After the use of radio has been proven feasible, a further step can be taken to decide between the use of digital or analog radio facilities.

9.2 A digital radio system has three distinct advantages over an analog radio system: less degradation of quality due to fades above threshold, easy interface with FCM carrier and less costly to add channels. In some instances a digital system can also be more cost

effective, depending on the frequency band used, channel capacity requirements, and the number of repeaters and paths required. One advantage an analog radio system has over a digital system is more efficient use of spectrum space. For example, one RF channel at 2 GHz can carry 252 analog multiplex channels but only 144 digital multiplex channels at the current state-of-the-art in digital design.

9.3 See Figure 3 for a graph of digital and analog channel noise characteristics versus received signal level. Note that the digital signal maintains the same channel quality during a fade occurrence until a certain threshold is reached, while the analog signal channel quality decreases linearly, one dB for each dB decrease in received signal level after the knee of the curve. For a system needing high quality circuits and reliability, digital equipment could be used to meet the requirements. Another feature of a digital radio system is that noise is not additive over tandem paths as it is in an analog radio system, since new digital signals are regenerated at repeater sites before retransmission.

9.4 If PCM carrier is used throughout a system, a digital radio can be used to essentially extend the carrier over wireless facilities, with no special interfacing or conversions involved. If system carrier facilities are predominantly analog, and a digital radio system is used, conversion from analog to digital signals would be necessary, resulting in added costs & more equipment to maintain. Likewise, in a telephone system that uses a lot of PCM carrier, the use of analog radio facilities would result in added costs and maintenance expense, and the full noise advantage of a digital signal would not be realized. Constructing a new digital radio system in an analog telephone system could be advantageous if system engineering studies indicate future usage of digital switches or digital wireline facilities. Engineering judgement must be used to determine whether digital or analog radio facilities would be most beneficial for a telephone system.

10. PRICING MICROWAVE SYSTEMS

10.1 Initial and PWAC costs should be considered when selecting the type of facility to provide the required circuits. Various plans should be examined on a PWAC cost basis as well as a system basis, and the most economically and technically feasible plan chosen. Annual cost factors can be obtained from REA TE & CM section 218, "Plant Annual Cost Data for System Design Purposes."

10.2 The cost components of a microwave system can be seen in table I. The prices shown are costs that were current in 1978, and are shown as examples. For actual up-to-date costs, the various suppliers of microwave equipment should be consulted. To price a microwave system add the individual system components cost plus 20% to cover installation and contingencies. Costs for land, passive repeaters, power, generators or other components which will be included in the system must also be added to estimate the complete system cost.

11. EXAMPLES OF COSTS FOR ANALOG AND DIGITAL RADIO SYSTEMS

11.1 An example is given for a cost comparison between digital and analog radio facilities at 2 GHz and 80 channels, with two

paths and an active repeater. No channel ends are dropped at the repeater site. Also assume 8' X 10' X 12' buildings and 100' guyed towers at all locations, 200 amp-hour battery supplies at the terminal ends, and a 400 amp-hour supply at the active repeater. Since an active repeater is essentially two RF terminals back-to-back, a total of four radio terminals are required. The cost can then be computed for an analog system:

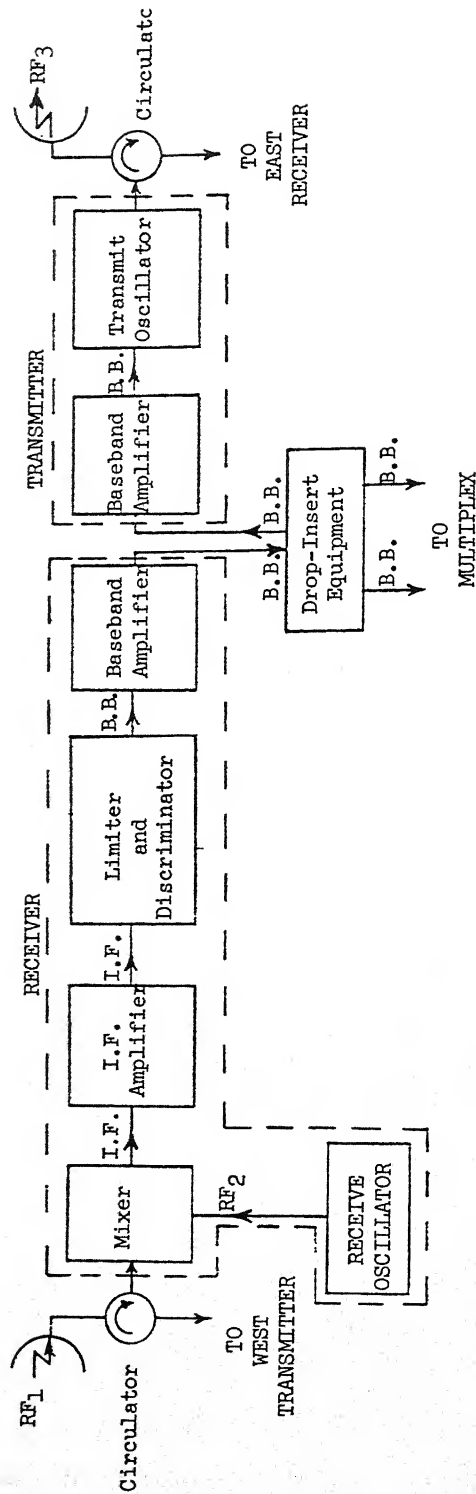
Four 2 GHz RF terminals	\$ 48,000
160 channel ends @700 per channel end	112,000
Three 8' X 10' X 12' buildings	24,000
Three 100' guyed towers @\$100/ft.	30,000
800 amp-hour total battery supply of \$20/AH	16,000
Four antennas and accessories	<u>12,000</u>
SUB-TOTAL for equipment	\$242,000
20% of above total for labor and contingencies	<u>48,400</u>
GRAND TOTAL	\$290,400

For the digital case:

Four 2 GHz RF terminals	\$100,000
160 channel ends @\$200 per channel end	32,000
Three 8' X 10' X 12' buildings	24,000
Three 100' guyed towers at \$100/ft.	30,000
800 amp hour (total) battery supply @\$20/A.H.	16,000
Four antennas and accessories	<u>12,000</u>
SUB-TOTAL for equipment	214,000
20% of above total for labor and contingencies	<u>42,800</u>
GRAND TOTAL	\$256,800

11.2 From the example above, the digital system would be cheaper than the analog system, but this may not hold true in all cases. At 2 GHz the channel capacity could be an economic factor. There are 252 analog channels available on one radio at 2 GHz, while each digital radio can currently carry only 144 channels, requiring two digital radios to carry the same number of channels as one analog radio. When making economic decisions on a microwave system design, the number of channels available for an analog or digital system can be a big factor. Figures 9A and 9B give examples of economic comparisons of analog and digital radio systems at 2 GHz, relative to the voice channels needed and number of radio paths. These examples assume a digital radio with a capacity of 96 channels on one polarization. The number of radio paths and active repeaters that are needed are generally a large factor in the total system cost. It should be noted that these examples include the cost of analog or PCM multiplex. If the signals to be transmitted over radio have already been digitally encoded, then the cost of the PCM multiplex is avoided and the economics would be even more in favor of the digital radio transmission system.

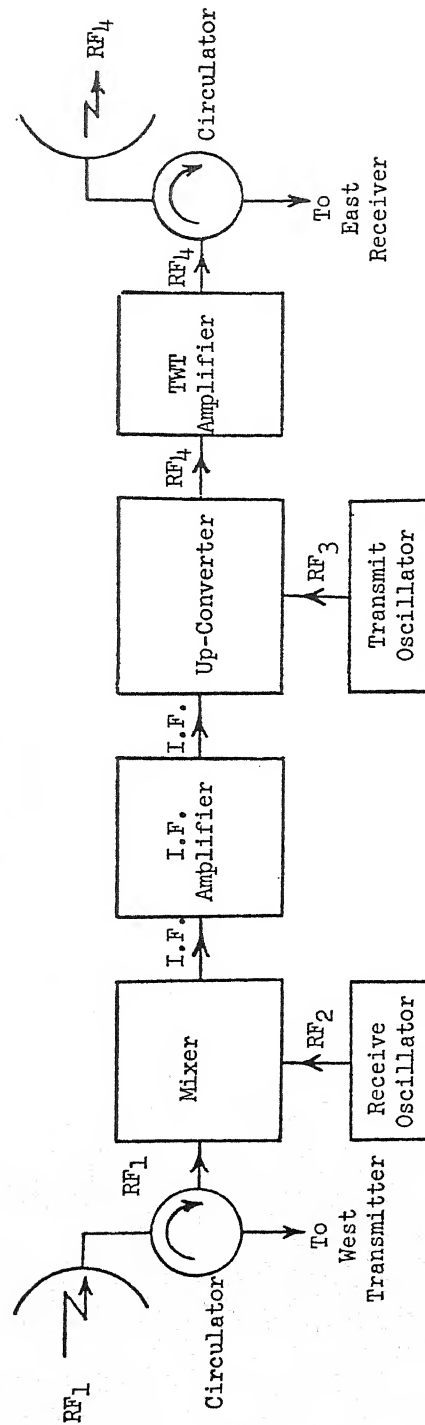
REMODULATING REPEATER



- RF_1 : Frequency of received microwave signal
- RF_2 : Frequency of receiver local oscillator
- I.F.: Intermediate frequency of receiver
- B.B.: Baseband frequencies
- RF_3 : Frequency of transmitted microwave signal

FIGURE 1

HETERODYNE REPEATER



- RF_1 : Frequency of received microwave signal
- RF_2 : Frequency of receive oscillator
- I.F.: Intermediate frequency of repeater
- RF_3 : Frequency of transmit oscillator
- RF_4 : Frequency of transmitted microwave signal

FIGURE 2

REMODULATING REPEATER

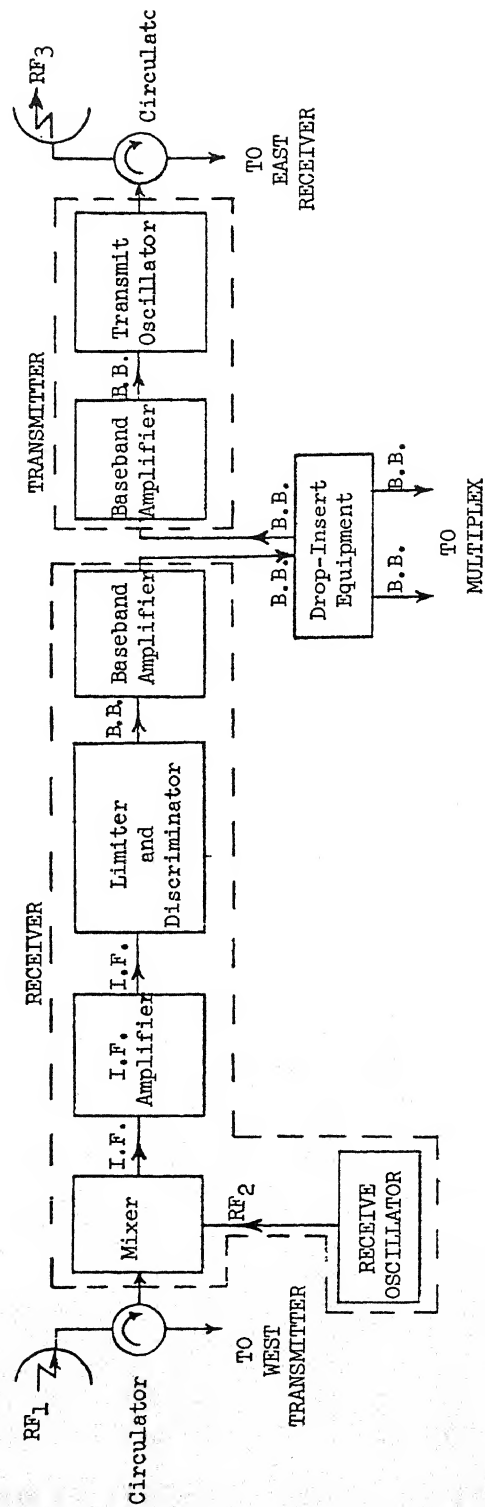
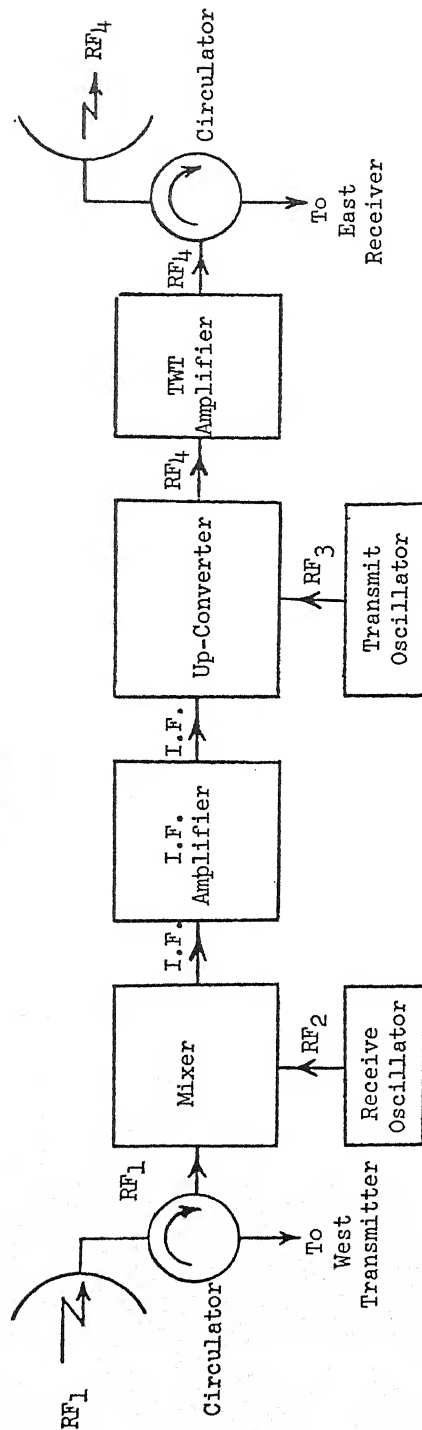


FIGURE 1

HETERODYNE REPEATER



- RF_1 : Frequency of received microwave signal
- RF_2 : Frequency of receive oscillator
- I.F.: Intermediate frequency of repeater
- RF_3 : Frequency of transmit oscillator
- RF_4 : Frequency of transmitted microwave signal

FIGURE 2

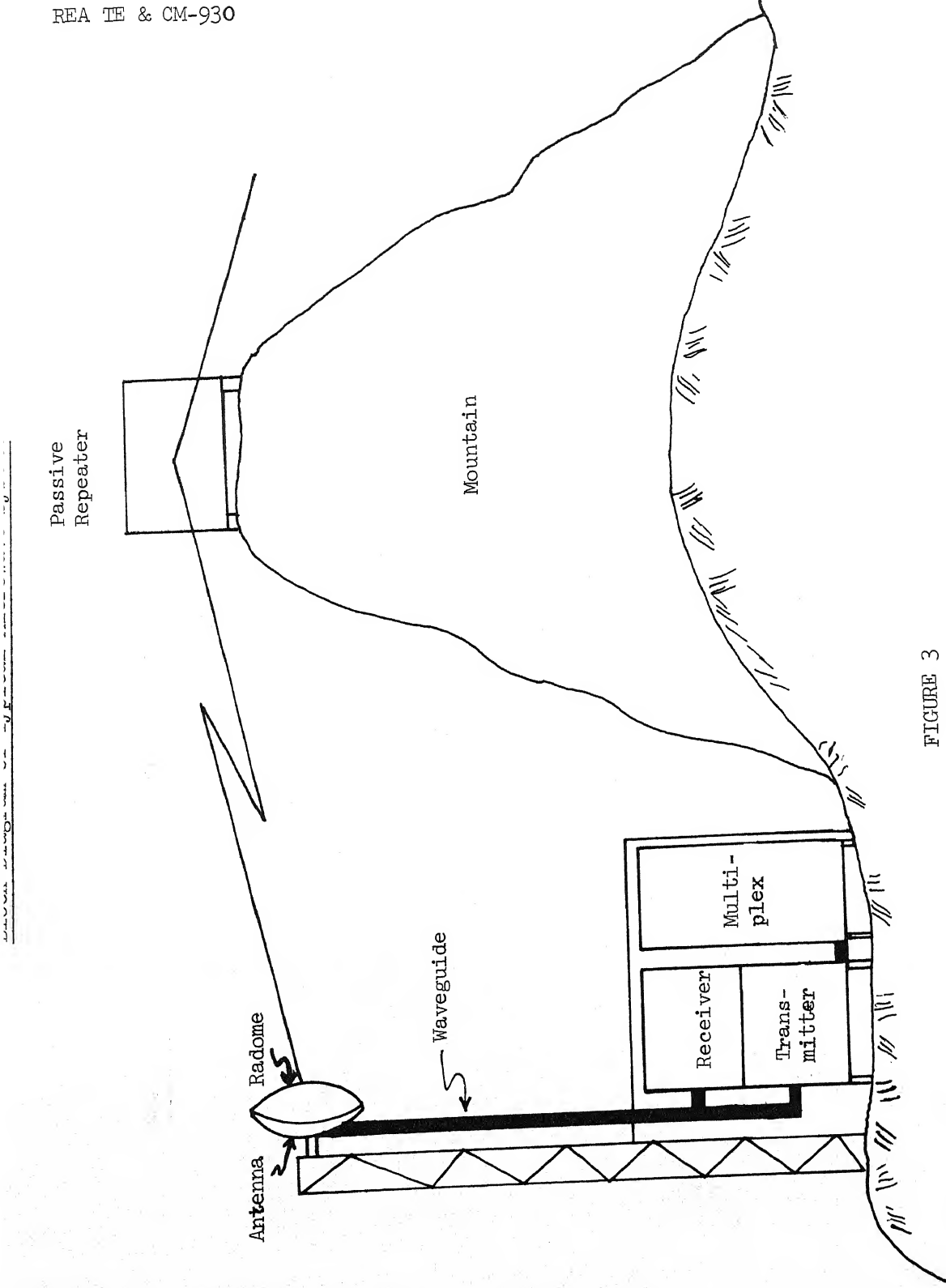


FIGURE 3

BASIC RF EQUIPMENT ARRANGEMENT FOR A TWO HOP SYSTEM

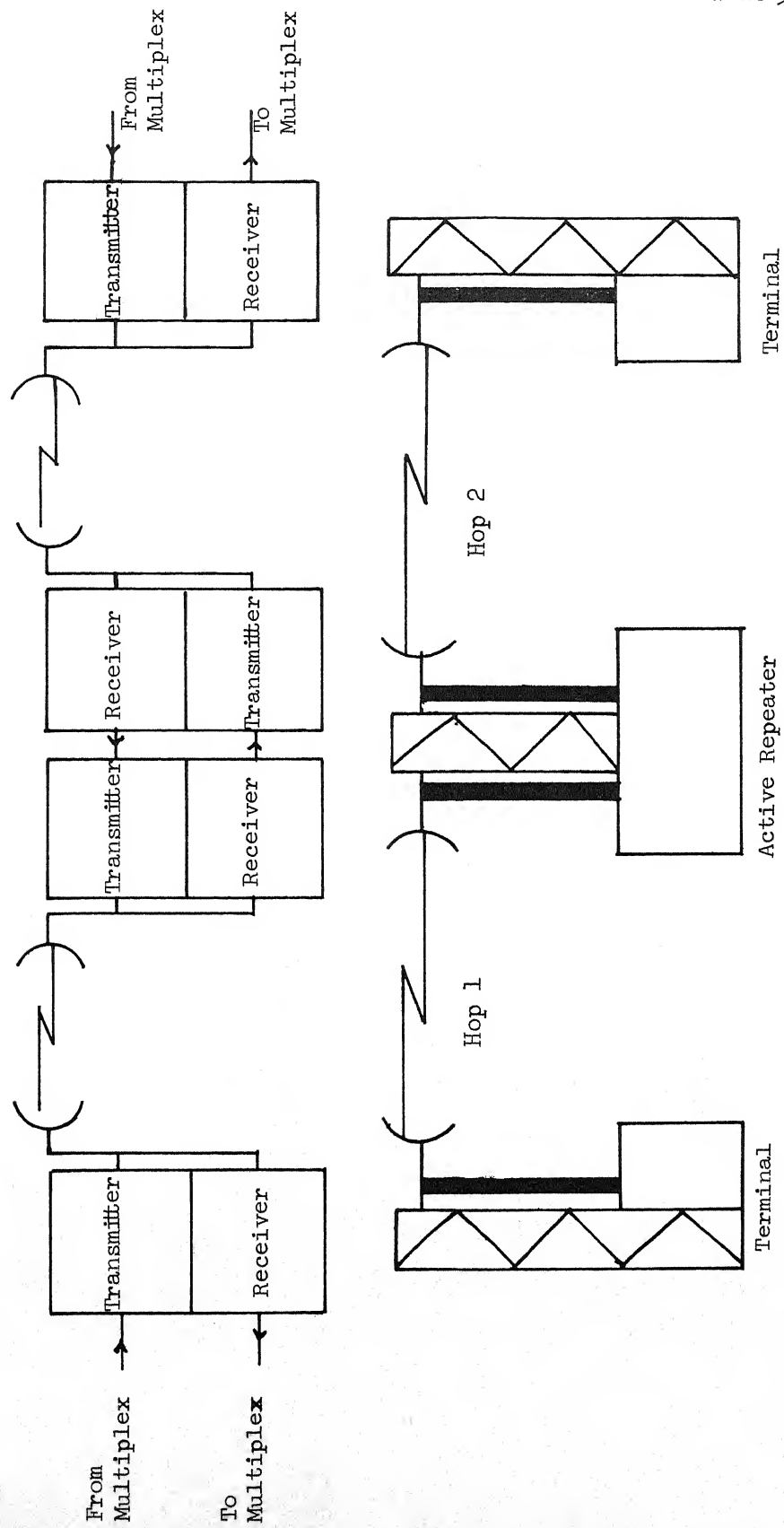
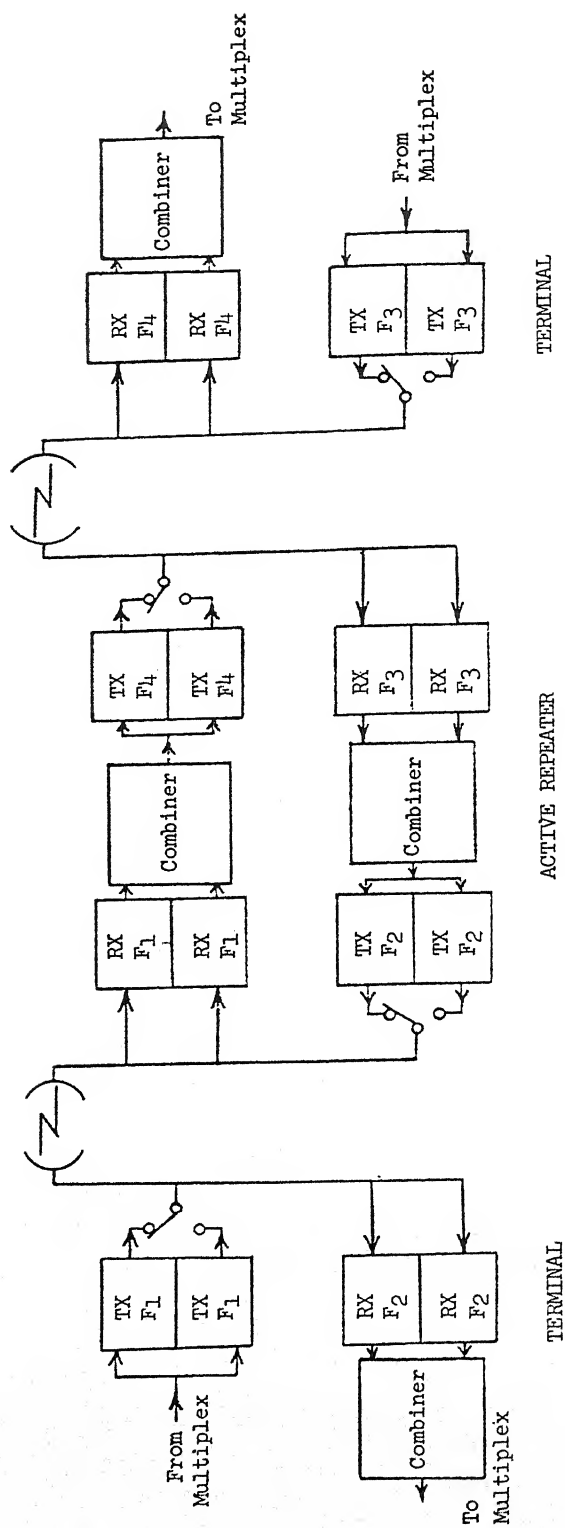


FIGURE 4

HOT STANDBY ARRANGEMENT FOR A TWO HOP SYSTEM



TX: Transmitter
RX: Receiver

FIGURE 5

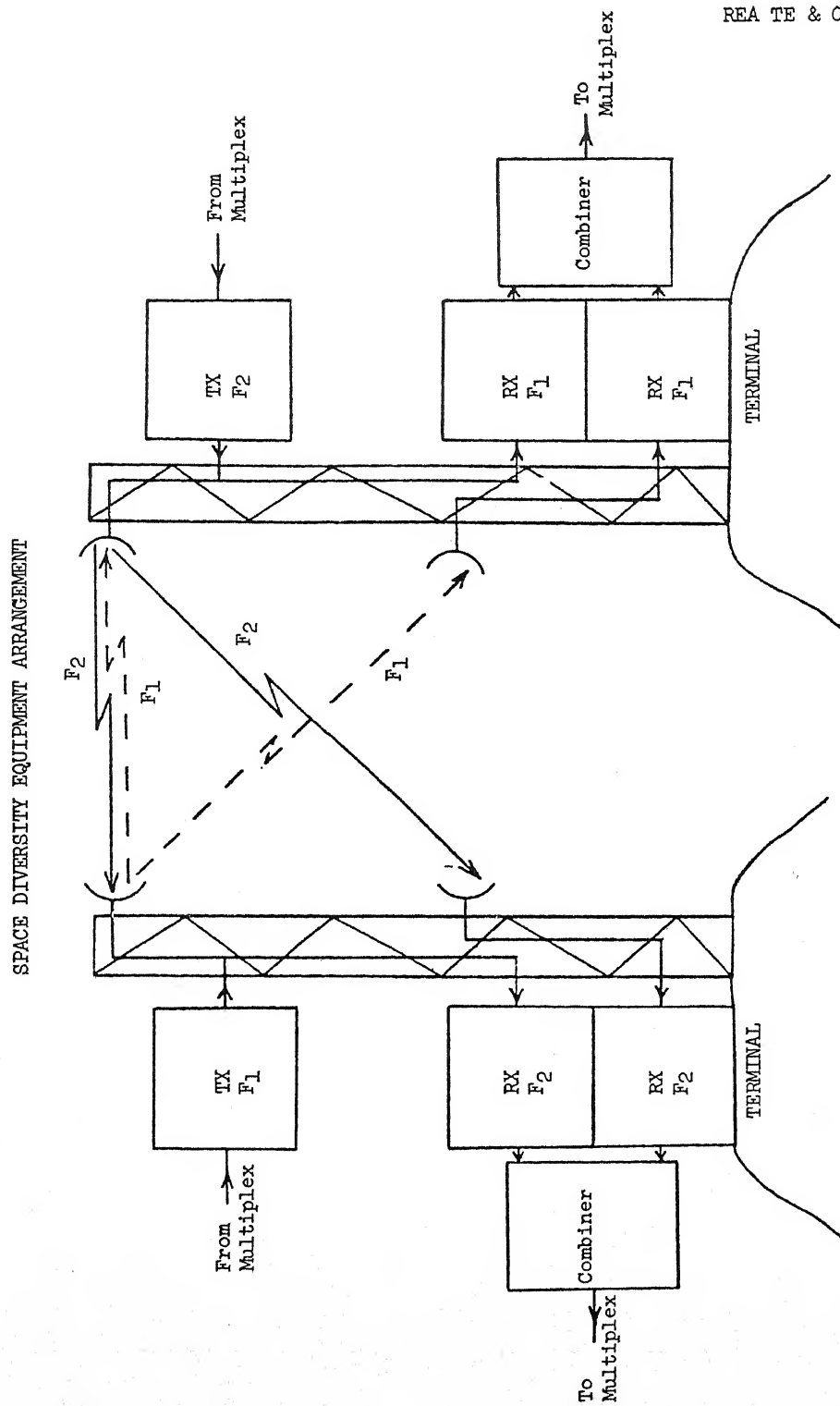


FIGURE 6

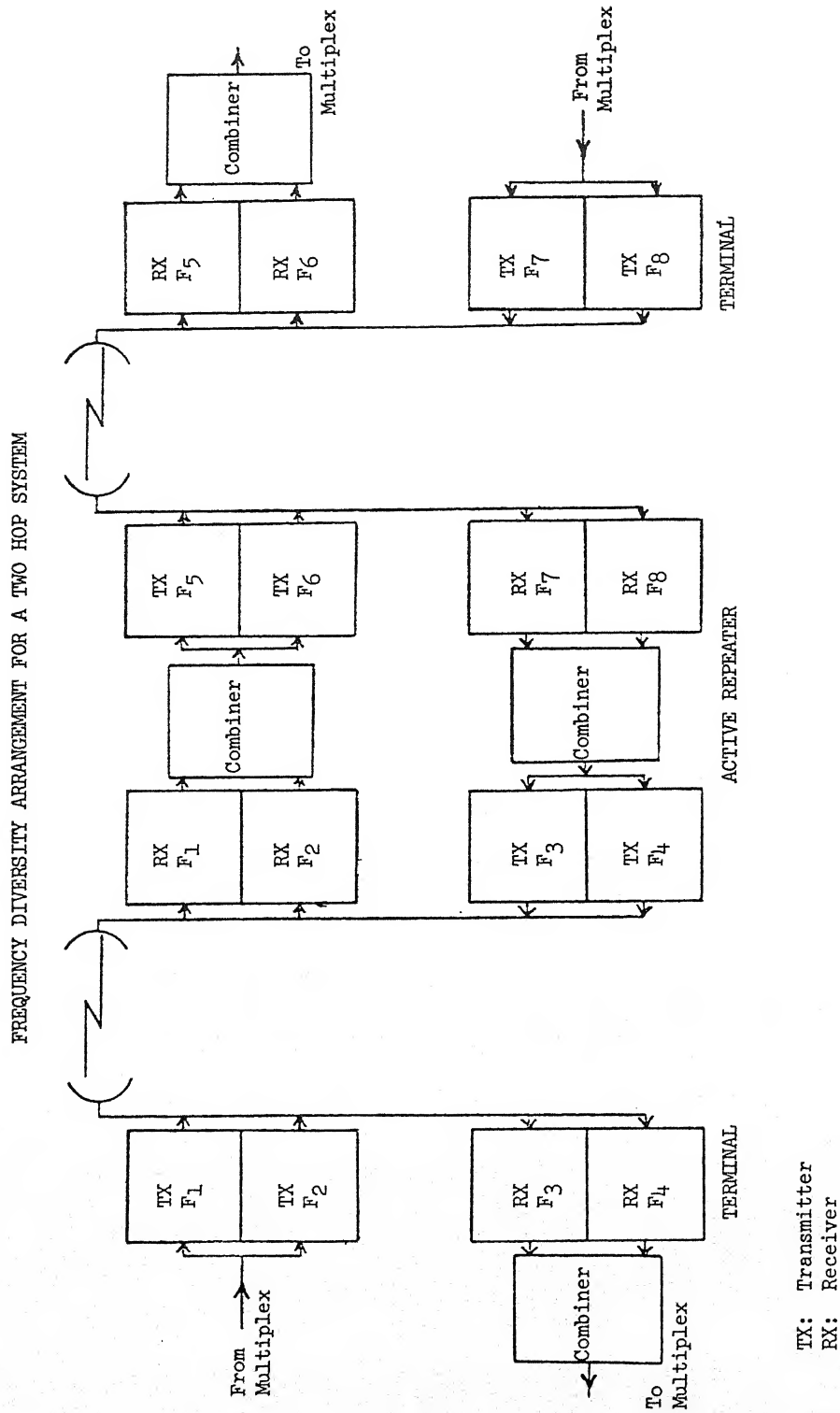


FIGURE 7

FIGURE 8
MICROWAVE SYSTEM NOISE
ANALOG VS. DIGITAL

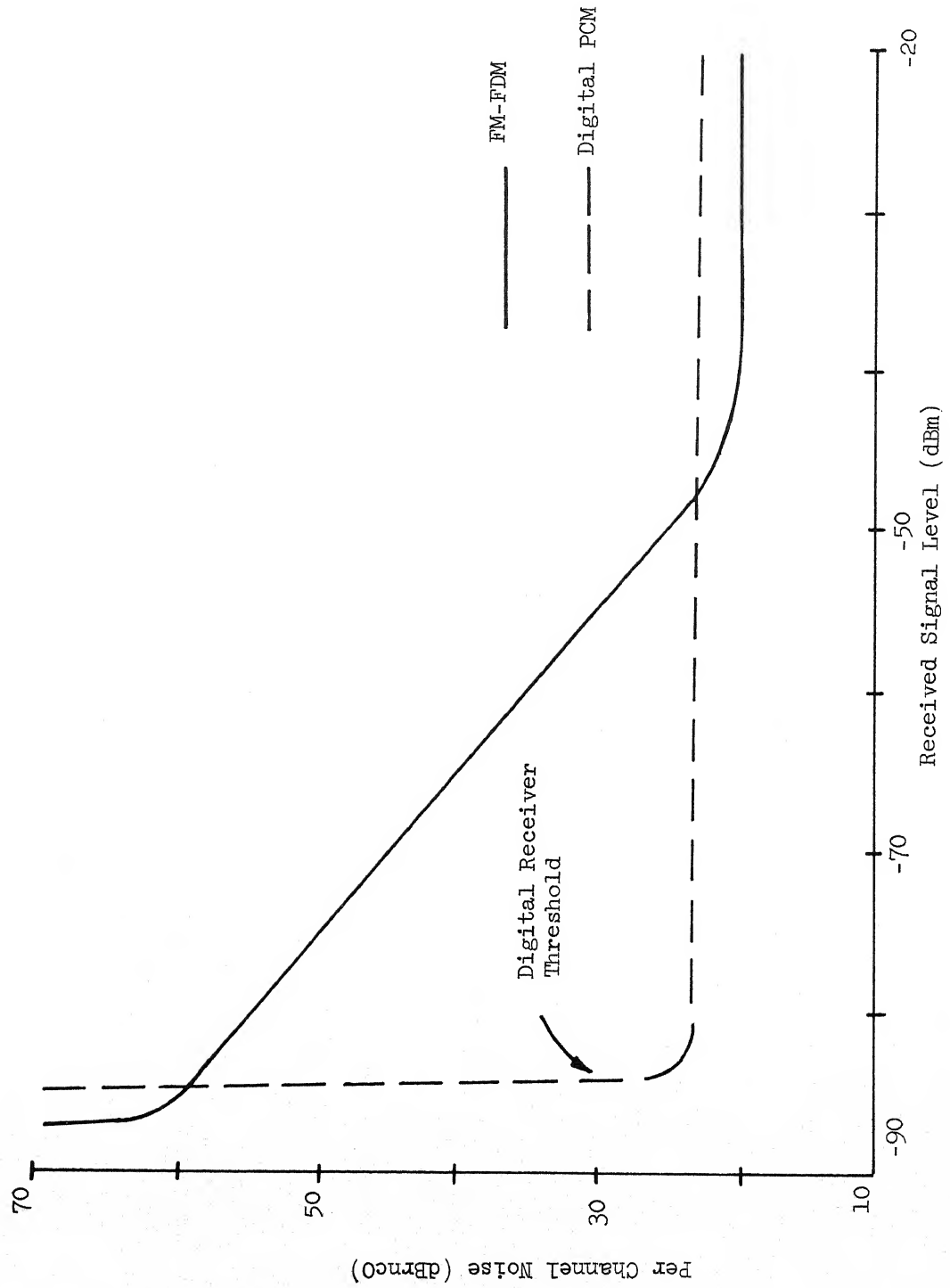


FIGURE 9A
ONE-HOP COST COMPARISON EXAMPLE
2 GHz DIGITAL vs. ANALOG
(Assumes digital radio with 96 channel
capacity on one polarization)

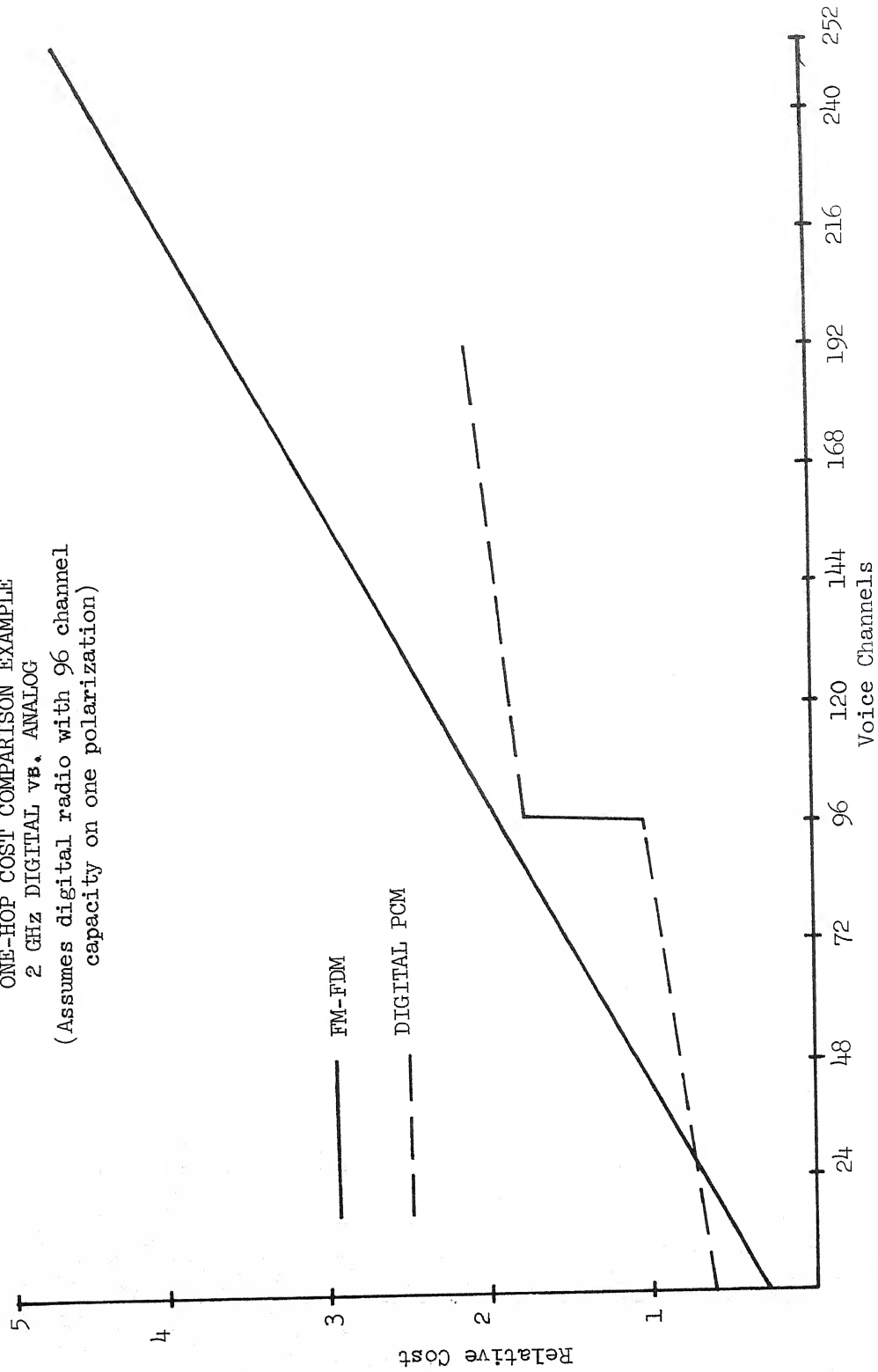


FIGURE 9B

THREE-HOP COST COMPARISON EXAMPLE
 2 GHz DIGITAL vs. ANALOG
 (Assumes digital radio with 96 channel
 capacity on one polarization)

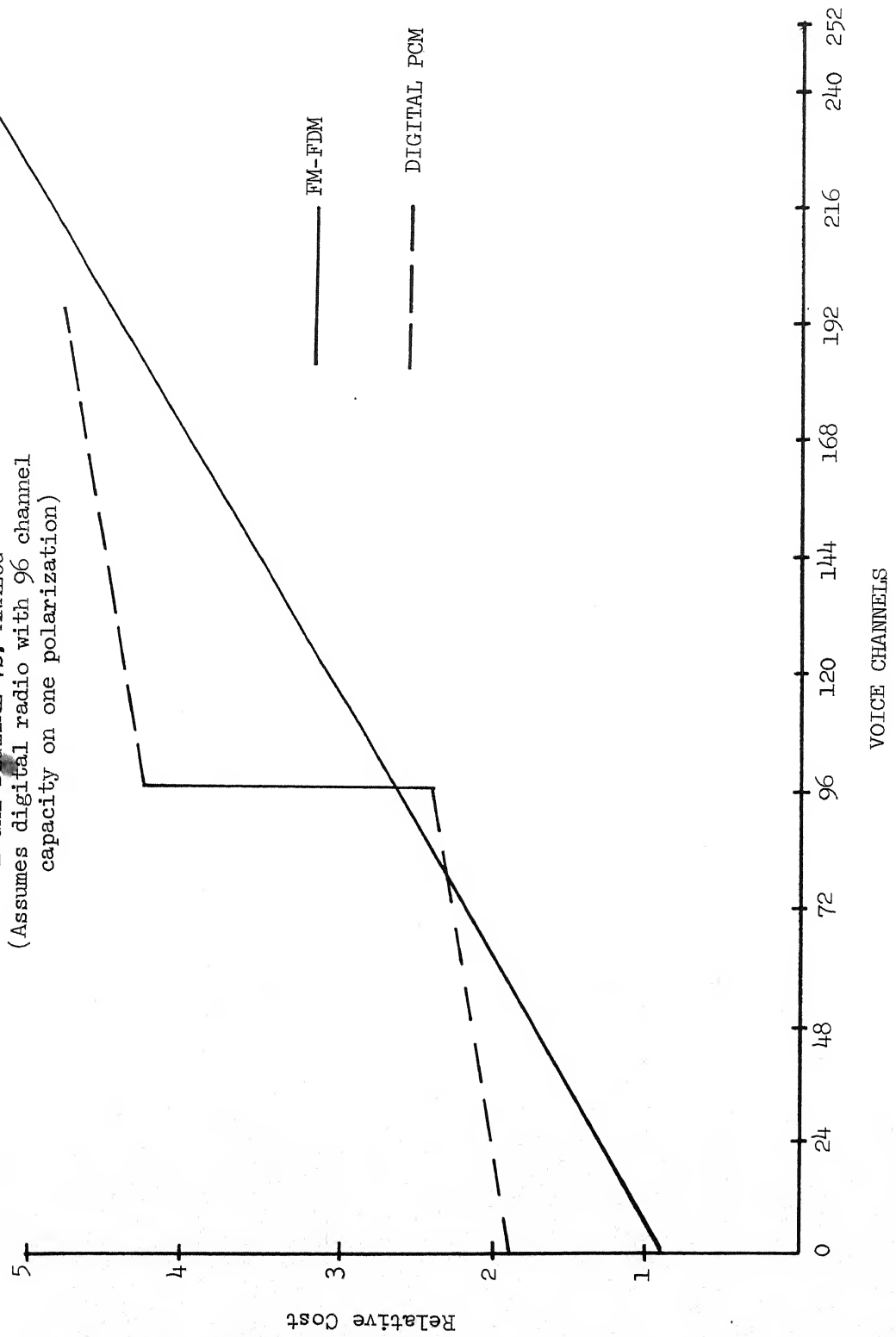


TABLE I

Typical Microwave Radio System Costs

RF Terminals

	<u>Frequency</u>	<u>Cost</u> (including hot standby protection)
<u>Analog:</u>	2GHz	\$12,000
	6GHz	\$16,000
	11GHz	\$20,000
<u>Digital:</u>	2GHz	\$25,000
	6GHz	\$45,000
	11GHz	\$50,000

Multiplex

Analog	\$700/channel end
Digital	\$200/channel end

Towers

	<u>1st 50 feet</u>	<u>Above 50 feet</u>
GUYED	\$100/foot	\$100/foot
SELF-SUPPORTING	\$100/foot	\$300/foot

Parabolic Antennas

Antenna Diameter (feet)	4	6	8	10	12	15
Price	\$800	\$1000	\$1500	\$2100	\$4400	\$10,000

Battery Supply - \$20 per amp-hourBuilding - 8' x 10' x 12' - \$8000

Add	20%	Labor, Miscellaneous
	10%	Electronic Spare Parts (10% of cost of Electronics)
	10%	Test Equipment (10% of cost of Electronics)

